GUIDELINES
FOR
CEMENT CONCRETE MIX DESIGN
FOR PAVEMENTS

(Third Revision)

Published by:

INDIAN ROADS CONGRESS

Kama Koti Marg,
Sector-6, R.K. Puram,
New Delhi-110 022

NOVEMBER, 2017

Price : ₹ 500/-
(Plus Packing & Postage)

First Published	:	August, 1972
First Revision	:	December, 1976
Second Revision	:	September, 2008
Reprinted	:	June, 2009
Reprinted	:	March, 2010
Reprinted	:	July, 2011
Reprinted	:	October, 2014
Third Revision	:	November, 2017

Printed by India Offset Press, Delhi - 110 064
500 Copies

CONTENTS

ABBREVIATIONS

Cementitious Material	–	cm
Ground Granulated Blast Furnace Slag	–	GGBFS
High Range Water Reducing Admixtures	–	HRWRAS
High Range Water Reducing Agents	–	HRWRA
High Strength Concrete	–	HSC
Ordinary Portland Cement	–	OPC
Pervious Concrete	–	PC
Portland Pozzolana Cement	–	PPC
Portland Slag Cement	–	PSC
Pavement Quality Concrete	–	PQC
Recycled Concrete Aggregate	–	RCA
Ready Mix Concrete	–	RMC
Saturated Surface Dry	–	SSD
Water Cement Ratio	–	w/c
Water Cementitious Material Ratio	–	w/cm

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GUIDELINES FOR CEMENT CONCRETE MIX DESIGN FOR PAVEMENTS (THIRD REVISION)

INTRODUCTION

Concrete has become an indispensable construction material. According to the present state-of-the-art, concrete has bypassed the stage of mere four component system, that is, cement, water, coarse aggregate and fine aggregates. It can be a combination of far more number of ingredients, for example a judicious combination of ingredients from more than ten materials. In the recent past, apart from the four ingredients mentioned above, and some more ingredients namely fly ash, ground granulated blast furnace slag, silica fume, rice husk ash, metakaoline, superplasticizer and fibres are generally used in concrete. Hence, it is all the more, plasticizers and retarders, accelerators and air entraining agents essential at this juncture to have general guidelines on proportioning the ingredients in concrete mixes. The need for the guidelines has been further enhanced by the importance given to proportioned concrete mixes in different specifications including IS:456.

The objective of design of concrete mixes is to arrive at the most economical and practical combinations and proportions of different ingredients to produce concrete that will meet the performance requirements under specified conditions of use. An integral part of concrete mix proportioning is the preparation of trial mixes and effecting adjustments to such trials to strike a balance between the requirements of placement, that is, workability and strength, concomitantly satisfying durability requirements.

Concrete has to be of satisfactory quality both in its fresh and hardened states. This task is best accomplished by trial mixes arrived at by the use of certain established relationships among different parameters and by analysis of data already generated thereby developing a basis for judicious combination of all the ingredients involved. The basic principles which underline the proportioning of mixes are Abram's law for strength development and Lyse's rule for making mix with adequate workability for placement in a dense state so as to enable the strength development as contemplated. From practical point of view, compressive strength is often taken as an index of acceptability. This does not necessarily satisfy the requirements of durability unless examined under specific context. Mix proportioning is generally carried out for a particular compressive strength or flexural strength requirements ensuring that fresh concrete of the mix so proportioned possesses adequate workability for placement without segregation and bleeding while attaining a dense state.

Proportioning of concrete mixes can be regarded as a procedure set to proportion the most economical concrete mix for specified durability and grade for required site conditions. The basic principle of the concrete mix design is to select the proportion of all the ingredients on the basis of their absolute volume and taking total absolute volume of concrete 1 m^3. In the present code apart from Guidelines for Cement Concrete Mix Design for Pavement of standard grade of concrete, approach to mix proportioning for high strength concrete and pervious concrete is also introduced. In the present Guidelines, the absolute volume of air

has been considered as 1.5 per cent for 9.5 mm, 1.0 per cent for 19 mm and 0.8 per cent for 31.5 mm maximum size of aggregate.

As a guarantor of quality of concrete in the construction, the contractor should carry out mix proportioning and the Engineer-in-Charge should approve the mix so proportioned. The mix design method given in these Guidelines is to be regarded as Guidelines only, to arrive at an acceptable proportions satisfying the requirement of placement, development of strength with age and durability.

The Draft IRC:44 "Guidelines for Cement Concrete Mix Design for Pavements" (Third Revision) was taken up by the Rigid Pavement Committee (H-3). The revised draft was prepared by Sub Group comprising of Shri V.V. Arora, Dr. S.C. Maiti, Shri J.B. Sengupta, Shri Binod Kumar, Dr. Pardeep Kumar Gupta and Shri Suresh Kumar. The draft was deliberated in a series of meetings. The H-3 Committee finally approved the draft document in its meeting held on 15th October, 2016 and decided to send the final draft to IRC for placing before the HSS Committee.

The Composition of H-3 Committee is as given below:

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The Highways Specifications & Standards Committee (HSS) considered and approved the draft document in its meeting held on 23rd June, 2017. The Executive Committee in its meeting held on 13th July, 2017 considered and approved the same document for placing it before the Council. The Council in its 212th meeting held at Udaipur on 14th and 15th July, 2017 considered and approved the draft IRC:44 "Guidelines for Cement Concrete Mix Design for Pavements" (*Third Revision*) for publishing.

In this third revision, the following major modifications have been made:

(a) In the present document Guidelines for Cement Concrete Mix Design for Pavement of standard grade of concrete, approach to mix proportioning for high strength concrete and pervious concrete are also introduced.

(b) The guidelines modify the procedure to fix the target mean strength for mix proportioning based on flexural strength or compressive strength and for each case two different equations are given and it is recommended to adopt the higher value as target mean strength. The recommended combined grading requirement of fine aggregate and coarse aggregate is also introduced.

(c) The maximum size of coarse aggregate for pavement construction is modified to 31.5 mm and the sieve sizes of aggregates are tuned to MORTH Specifications.

(d) The requirements for selection of standard deviation, air content, water-cement ratio, water content and estimation of quantity of coarse and fine aggregate, trial mixes, illustrative examples have been reviewed and accordingly modified.

(e) Illustrative examples of concrete mix proportioning for standard grade concrete based on both i.e. flexural strength and compressive strength, high strength concrete and pervious concrete are given as Annexure. The uses of mineral and chemical admixture as one of the ingredients have been included.

(f) The adjustment on water content and aggregate content is also explained if the aggregates lying are in wet or dry condition.

In this revision, assistance has also been derived from ACI:211.1 (Re-approved 2014) 'Standard Practice for Selecting Proportions for Normal, Heavyweight, Mass Concrete, High Strength and pervious Concrete', American Concrete Institute and also from IS:10262.

1 SCOPE

1.1 This standard lays down the guidelines for design of concrete mixes as per the requirements by proportioning the concrete making materials including other supplementary materials. The proportioning of materials is carried out to achieve specified characteristic strength, workability and durability requirements. This standard does not cover mix design for roller compacted concrete/dry lean concrete for which seperate IRC guidelines are available.

2 DEFINITIONS

2.1 For the purpose of these guidelines, the definitions given in IS:456-2000, IS:4845 and IS:6461 (Part-I to IV) shall apply. The commonly used terms are given below:

2.2 Characteristic Strength of Concrete

The characteristics strength is defined as the strength of concrete below which not more than 5 per cent of the test results are expected to fall.

2.3 Pozzolana

An essentially siliceous material which while in itself possessing little or no cementitious properties will, in finely divided from and in the presence of water, react with calcium hydroxide at ambient temperature to form compounds possessing cementitious properties. The Pozzolanic materials are Flyash (pulverized fuel ash), Silica fume and Metakaoline etc.

2.4 Granulated Blast Furnace Slag

Blast furnace slag is non-metallic product consisting essentially of glass containing silicates and alumina silicates of lime and other bases, which are developed simultaneously with iron in blast furnace or electric pig iron furnace. Granulated slag is obtained by further processing the molten slag by rapidly chilling or quenching it with water or steam and air. Blast furnace slag in granulated form is used for the manufacture of hydraulic cement.

2.5 Aggregate

Granular material, generally inert & such as natural and manufactured sand , natural & crushed gravel, crushed stone, crushed iron or steel slag, recycled concrete aggregate or combination thereof used for making concrete or mortar.

2.6 Coarse Aggregate

Aggregate most of which is retained on 4.75 mm IS Sieve.

2.7 Fine Aggregate

Aggregates most of which passes 4.75 mm IS Sieve and containing only so much coarser material as is permitted for various grading zones in the specification. Fine aggregate shall consist of natural sand, crushed stone sand or combination thereof conforming to the requirement of IS:383 for pavement concrete.

2.7.1 *Natural sand*

Fine aggregate resulting from the natural disintegration of rock and/or which has been deposited by streams or glacial agencies.

2.7.2 *Crushed stone sand*

Fine aggregate produced by crushing hard stone or natural gravel.

2.7.3 *Mixed sand*

Sand produced by blending natural sand and crushed stone sand or crushed gravel sand in suitable proportions.

2.7.4 *Manufactured fine aggregates*

Fine aggregate produced from other than natural sources either by processing materials, using thermal & other processes such as separation, washing, crushing or scrubbing etc. For example: Iron slag & Steel slag, Copper slag, and Recycled Concrete Aggregates (RCA).

2.8 Water/Cement Ratio (w/c)

The water/cement ratio (w/c) is calculated by dividing the mass of the mixing water by the mass of the cement.

2.9 The Water/Cementitious Materials Ratio (w/cm)

The Water/Cementitious Materials Ratio (w/cm) is the ratio of mass of the mixing water and the mass of the cement, fly ash and other cementitious materials.

2.10 Cementitious Materials (cm)

The cement and permitted mineral admixtures such as flyash, silica fume, metakaoline and ground granulated blast furnace slag used in concrete.

2.11 Pervious Concrete

Cement concrete proportioned with sufficient interconnected voids that result in a highly permeable material, allowing water to readily pass.

2.12 Saturated Surface Dry

Saturated Surface Dry is the condition of an aggregate in which the surface of the aggregate is dry i.e. surface adsorption would no longer take place, but inter-particle voids are saturated with water.

3 MATERIALS

3.1 Cement

Any of the following types of cement capable of achieving the design strength may be used with prior approval of the Engineer-in-Charge subject to the condition that satisfy the Specifications in respective IS codes. The minimum 28-day compressive strength of cement should not be less than 43 MPa.

(i) Ordinary Portland Cement, 43 Grade & 53 Grade, IS:269

(ii) Portland - Pozzolana Cement, IS:1489, Part I

(iii) Portland Slag Cement, IS:455

(iv) Composite Cement, IS:16415

3.2 Admixtures

Admixtures may be mineral or chemical which can be used for getting the desired properties of mix.

3.2.1 *Retarders, plasticizers and superplasticiser*

Retarders, plasticisers and super plasticisers conforming to IS:9103 may be used upto 0.5 per cent, 1 per cent and 2 per cent by mass of cementitious materials respectively. However, the dosages of polycarboxylate based admixture shall not exceed 1.0 per cent. A higher % of above admixtures may be used, if agreed upon by the manufacturer and the contractor based on performance tests related to workability, setting time and early age strength as stipulated in IS:456.

3.2.2 *Air entraining admixture*

In freezing weather, use of air entraining admixture is recommended to counter the freezing and thawing effect with 5.5 ± 1.5 per cent for 31.5 mm maximum size of aggregate and 6.0±1.5 per cent for 19 mm maximum size of aggregate.

The air-entraining admixture may be used for improving the cohesiveness of the mix and to reduce bleeding, the total quantity of air in air-entrained concrete as a percentage of the volume of the concrete shall have 4.5 ± 1.5 per cent entrained air for 31.5 mm maximum size of aggregate and 5.0 ± 1.5 per cent entrained air for 19 mm maximum size of aggregate.

3.3 Fibers

As stipulated in IRC:SP:46 and IS: 456, fibers may be added to concrete for special applications to enhance properties. The fibers may be carbon, steel fibers or polymeric synthetic fibers and shall be uniformly dispersed in the concrete mass at the time of concrete production.

3.4 Aggregates

Aggregates for pavement concrete shall comply with IS:383 except for grading and any other specific requirement given in IRC:15.

3.4.1 *Coarse aggregate*

Coarse aggregate shall consist of clean, hard, strong, dense, non-porous and durable pieces of crushed stone or crushed gravel and shall be devoid of pieces of disintegrated stone, soft, flaky, elongated, very angular or splintery pieces. The combined flakiness and elongation index shall not be more than 35 per cent. Aggregate Impact Value (AIV) shall not be more than 30 per cent. Limestone aggregate may be used conforming to IS:383. The maximum size of coarse aggregate shall not exceed 31.5 mm in PQC.

Continuously graded aggregates may be used, depending on the combined grading of the coarse and fine aggregate. No aggregate which has water absorption more than 2 per cent shall be used in concrete mix. Wherever aggregates of 2 per cent water absorption are not available, higher value of water absorption subjected to the maximum cf 3 per cent may be allowed if other engineering properties are satisfied as per IS:383.

3.4.1.1 Size and grading of coarse aggregates

Coarse aggregates shall be supplied in the nominal sizes. **Table 1** may be used as guidance for procurement.

Table 1 Coarse Aggregates for Pavement Quality Concrete

Sieve Designation mm	Percentage Passing for Single-Sized Aggregate of Nominal Size			
	31.5 mm	19 mm	12.5 mm	9.5 mm
37.5	100	-	-	-
31.5	85 - 100	-	-	-
19	0 - 20	85 - 100	-	-
16	-	-	100	-
12.5	-	-	85 - 100	100
9.50	0 - 5	0 - 20	0 - 45	85 - 100
4.75	-	0 - 5	0 - 10	0 - 20
2.36	-	-	-	0 - 5

3.4.2 *Fine aggregate*

Fine aggregates shall be free from soft particles, clay, shale, loam, cemented particles, mica and organic and other foreign matter. Fine aggregates which have water absorption more than 3 per cent shall not be used. The fine aggregate shall not contain material passing IS sieve No. 75 micron (wet sieving) more than the following:

i) Natural sand : 3 % by weight of natural sand

ii) Crushed Stone sand* : 12 % by weight of crushed stone

iii) Blend of natural sand and crushed stone sand shall not exceed 8 % by total weight of fine aggregates (IS:383)

Although IS:383 permits in the case of stone crushed sand, the fines passing 75 microns up to 15 per cent, this provision should be used with caution when crushed stone sand is used as fine aggregate and when the mix produced in the Laboratory and the field is satisfactory in all respects and complies with the requirement of Specification. The grading zone of fine aggregates as per IS:383 shall be within the limits as given in **Table 2**.

Table 2 Fine Aggregates Requirements

IS Sieve Designation	Percentage Passing for		
	Grading Zone-I	Grading Zone-II	Grading Zone-III
9.50 mm	100	100	100
4.75 mm	90 – 100	90 – 100	90 – 100
2.36 mm	60 – 95	75 – 100	85 – 100
1.18 mm	30 – 70	55 – 90	75 – 100
600 micron	15 – 34	35 – 59	60 – 79
300 micron	5 – 20	8 – 30	12 – 40
150 micron	0 – 10	0 – 10	0 – 10

Where the grading falls outside the limits of any particular grading zone of sieves other than 600-micron IS Sieve by an amount not exceeding 5 per cent for a particular sieve size, (subject to cumulative amount of 10 per cent), it shall be regarded as falling within that grading zone. This tolerance shall not be applied to percentage passing the 600-micron IS: Sieve or to percentage passing any other sieve size on the coarse limit of grading Zone I.

For crushed stone sands, the permissible limit on 150-micron IS: Sieve is increased to 20 per cent. The use of crushed stone sand is permitted in PQC. However, its percentage of fines passing 75 micron sieve (wet sieving) shall not exceed 12 per cent.

Zones here do not depict the location/region. They depict the gradation of fine aggregates in a descending order.

3.5 Combined Gradation of Fine and Coarse Aggregates

It is recommended to achieve the combined grading of fine and coarse aggregates as per **Table 3**. Graded coarse aggregates or single-sized coarse aggregates of nominal size shall be mixed in suitable proportions with fine aggregate to achieve the combined grading requirement of **Table 3**.

Table 3 Combined Aggregate Gradation for Pavement Quality Concrete

Sieve Designation	Percentage by weight Passing		
	31.5 mm Nominal Size	**26.5 mm Nominal Size**	**19 mm Nominal Size**
37.5 mm	100	100	100
31.50 mm	90 – 100	100	100
26.50 mm	85 – 95	90 – 100	100
19.0 mm	68 – 88	75 – 95	90 – 100
9.50 mm	45 – 65	50 – 70	48 – 78
4.75 mm	30 – 55	30 – 55	30 – 58
600 micron	8 – 30	8 – 30	8 – 35
150 micron	0 – 10	0 – 10	0 – 12
75 micron (Wet Sieving)	0 – 5* 0 – 2**	0 – 5* 0 – 2**	0 – 5* 0 – 2**

*Crushed Sand, **Natural sand

3.6 Mineral Admixtures

The following materials may be added at site as mineral admixtures as per their availability and subject to regulations for their use. The percentages of mineral admixtures indicated below are recommendation only. If related specification gives different value, the specified value should be used.

3.6.1 *Pozzolanas*

Pozzolanic materials conforming to relevant Indian Standards may be used with the permission of the Engineer-in-Charge, provided uniform blending with cement is ensured.

i) Flyash conforming to Grade I of IS:3812 may be used as part replacement of Portland cement: Maximum dosage: 25 per cent by mass of cementitious materials

ii) Silica fume (as per IS:15388 and IS:456): The silica fume (very fine non-crystalline silicon dioxide) is a by-product of the manufacture of silicon, ferrosilicon or the like, from quartz and carbon in electric arc furnace. It is usually used in proportion of 5 to 10 per cent of the cementitious material content of the mix. Use of silica fume is generally advantageous for higher grades of concrete i.e. M50 and above.

iii) Metakaoline is obtained by calcination of pure or refined kaolintic clay at a temperature between 650 and 850° C followed by grinding to achieve a fineness of 700 to 900 m^2/kg. Metakaolin conforming to IS:16354 (under preparation) may be used upto 20 per cent of the cementitious material.

3.6.2 *Ground granulated blast furnace slag*

Factory manufactured ground granulated blast furnace slag conforming to IS:10875 (under preparation) upto 50 per cent by weight of cementitious material may be mixed at site with Ordinary Portland Cement of 43/53 Grade. Regular tests shall be conducted on GGBFS at a testing frequency of 1 test per 100 MT of slag to ensure the quality.

3.7 Water

Water used for mixing and curing of concrete shall be clean and free from injurious amounts of oil, salt, acid, vegetable matter or other substances harmful to the concrete. It shall meet the requirements stipulated in IS:456. Potable water is generally considered satisfactory for mixing and curing.

4 MIX DESIGN

For detailed mix design IS:10262 may be referred if necessary

4.1 Data for Mix Proportioning

The following data are required for mix proportioning of a particular grade of concrete:

a) Grade designation (required compressive strength/flexural strength)
b) Type of cement
c) Maximum nominal size of aggregate
d) Minimum cement/cementitious materials content and maximum water-cement/cementitious materials ratio to be adopted
e) Maximum cement content
f) Workability required at the time of placement
g) Time duration from mixing to placement
h) Method of transporting and placing
i) Degree of site control (good) or value of established standard deviation, if any
j) Type of coarse aggregate
k) Type of fine aggregate
l) Whether a chemical admixture shall or shall not be used and the type of chemical admixture and the extent of use
m) Whether a mineral admixture shall or shall not be used and the type of mineral admixture and the extent of use
n) Whether fibres shall or shall not be used and type and specification of fibres to be used
o) Any other specific requirement like early age strength requirement

4.2 Target Strength for Mix Proportioning

In order that not more than 5 per cent of test results are likely to fall below the characteristic strength, the concrete mix has to be design for higher target mean compressive strength (f'_{ck}) or flexural strength (f'_{cr}). The margin over characteristic strength is given by the following relation:

4.2.1 *Based on flexural strength*

$f'_{cr} = f_{cr} + 1.65 \times S_f$

OR

$f'_{cr} = f_{cr} + 0.55$

Whichever is higher.

Where

f'_{cr} = target mean flexural strength at 28 days, N/mm^2

f_{cr} = characteristic flexural strength at 28 days, N/mm^2

S_f = standard deviation of flexural strength, N/mm^2

4.2.2 *Based on compressive strength*

$f'_{ck} = f_{ck} + 1.65 \times S_c$

OR

$f'_{ck} = f_{ck}$ + X (The value of X is given in **Table 4**)

Whichever is higher

Table 4 Value of X

Sl. No.	Grade of concrete	Value of X N/mm^2
1	M 30	5.0
2	M 35	
3	M 40	6.5
4	M 45	
5	M 50	
6	M 55	
7	M 60	
8	M 65 & above	8.0

where

f'_{ck} = Target mean compressive strength at 28 days, N/mm^2

f_{ck} = Characteristic compressive strength at 28 days, N/mm^2

S_c = Standard deviation of compressive strength, N/mm^2

4.3 Standard Deviation

The standard deviation for each grade of concrete shall be calculated separately.

4.3.1 *Standard deviation based on test results of samples*

a) Number of test results of samples – The total number of test results of samples required for calculation of standard deviation shall be not less than 30. Attempts should be made to obtain the 30 samples (taken from site), as early as possible, when a mix is used for the first time, to validate and improve the mix design (if required).

b) In case of significant changes in concrete – When significant changes are made in the production of concrete batches (for example changes in the materials used, mix proportioning, equipment or technical control), the standard deviation value shall be separately calculated for such batches of concrete.

c) Standard deviation to be brought up to date – The calculation of the standard deviation shall be brought up to date periodically and after every change of mix proportioning. The standard deviation should be checked every month subject to minimum 30 results to ensure that it is less than the value considered in mix design.

4.3.2 *Calculation of standard deviation*

Calculate the sample standard deviation, S, of the strength test records as follows:

- For a single group of consecutive test results:

$$S=\sqrt{\frac{\sum_{i=1}^{n}(X_i-\overline{X})^2}{(n-1)}} \qquad (1)$$

Where

S = sample standard deviation

n = number of test results considered

$\overline{X}$ = average of n test results considered, and

X_i = individual test result

- For two groups (mixes) of consecutive test results of same grade

$$S=\sqrt{\frac{(n_1-1)s_1^2+(n_2-1)s_2^2}{(n_1+n_2-2)}} \qquad (2)$$

Where

S = standard deviation for the two groups combined

S_1, S_2 = standard deviation for group 1 and 2, respectively, calculated in accordance with eq. (1-2)

n_1, n_2 = number of test results in group 1 and 2, respectively

4.3.3 *Assumed standard deviation*

Where sufficient test results for a particular grade of concrete are not available the value of standard deviation given in **Table 5** for mix designs based on flexural strength and **Table 6** for mix designs based on compressive strength may be assumed for proportioning of mix in the first instance. These values correspond to good degree of site control having proper storage of cement; weigh batching of all materials; controlled addition of water; regular checking of all materials, aggregate grading and moisture content; and periodical checking of workability and strength. As soon as the results of samples are available, actual calculated standard deviation shall be used and the mix re-proportioned accordingly. (However, when adequate past records for a similar grade exist and are justified to the designer a value of standard deviation different from that shown in **Table 5** for mix designs based on flexural strength and **Table 6** for mix designs based on compressive strength is permitted to be used).

Table 5 Assumed Standard Deviation Values for Mix Designs Based on Flexural Strength

Sl No.	Grade of concrete (Characteristics Flexural Strength in N/mm^2)	Assumed Standard Deviation N/mm^2
1	3.5	0.35
2	4.0	
3	4.5	0.40
4	5.0	
5	5.5	

Table 6 Assumed Standard Deviation Values for Mix Designs Based on Compressive Strength

Sl. No.	Grade of concrete	Assumed Standard Deviation N/mm^2
1	M 30	5.0
2	M 35	
3	M 40	
4	M 45	
5	M 50	
6	M 55	
7	M 60	
8	M 65	6.0
9	M 70	
10	M 75	
11	M 80	

Note: The above values shall also be applicable where Ready Mixed Concrete (RMC) is used.

4.4 Selection of Mix Proportions

4.4.1 *Estimation of air content*

Approximate amount of entrapped air to be expected in normal (non-air-entrained) concrete is given in **Table 7**.

Table 7 Approximate Air Content

Nominal Maximum Size of Aggregate, mm	Entrapped Air, as Percentage of Volume of Concrete
9.5	1.5
19	1.0
26.5	0.9
31.5	0.8

4.4.2 *Selection of water-cement ratio*

Since different cements, supplementary cementitious materials and aggregates of different maximum size, grading, surface texture, shape and other characteristics may produce concretes of different compressive strength for the same free water-cement ratio, the relationship between strength and free water-cement ratio should preferably be established for the materials actually to be used. In the absence of such data, the preliminary free water-cement ratio (by mass) corresponding to the design strength at 28 days may be selected from the established relationship, if available. Otherwise, the **Table 8** and **Table 9** given below may be used as a starting point for selection of water-cement ratio for the mix designs based on flexural strength and compressive strength respectively.

Table 8 Preliminary Selection of Water – Cement/Cementitious Materials Ratio for the Given Grade for Mix Designs Based on Flexural Strength

Sl. No.	Flexural Strength at 28-Day, N/mm^2	Approximate Water Cement/ Cementitious Materials Ratio	
		OPC-43 Grade	OPC-53 Grade
1	3.5	0.50	0.50
2	4.0	0.46	0.50
3	4.5	0.39	0.44
4	5.0	0.34	0.38
5	5.5	0.28	0.32

Table 9 Preliminary Selection of Water – Cement/Cementitious Materials Ratio for the Given Grade for Mix Designs Based on Compressive Strength

Sl. No.	Compressive Strength at 28-Day N/mm²	Approximate Water- Cement/ Cementitious Materials Ratio	
		OPC-43 Grade	OPC-53 Grade
1	32	0.47	0.50
2	37	0.43	0.48
3	42	0.39	0.45
4	48	0.36	0.42
5	53	0.33	0.38
6	58	0.30	0.35
7	65	0.27	0.32
8	68	0.24	0.29

While using PPC or PSC, the water cement ratio should be taken based on the 28 day strength of cement. In the absence of data on 28 day strength of cement for PPC or PSC, the w/c ratio values given for 43 grade OPC can be utilized for trials.

The Supplementary cementitious materials that is, mineral admixtures shall also be considered in water-cement ratio calculations and be referred as water-cementitious materials ratio.

The maximum water cement ratio shall be restricted to 0.40 for the respective grade as per IRC:15.

Water-cement ratio, for strengths other than as mentioned in **Tables 8 & 9**, may be interpolated.

4.4.3 *Selection of water content and chemical admixture (superplasticizer) content*

The water content of concrete is influenced by a number of factors such as aggregate size, aggregate shape, aggregate texture, workability, water-cement ratio, cement and other supplementary cementitious materials type and content, chemical admixture and environmental conditions. An increase in aggregates size, a reduction in water-cement ratio and slump, and use of water reducing admixtures will reduce the water demand. On the other hand increased temperature, cement content, slump, water-cement ratio, aggregate angularity and a decrease in the proportion of the coarse aggregate to fine aggregate will increase water demand.

The quantity of approximate mixing water per unit volume of concrete for saturated surface dry aggregate may be determined from **Table 10**. The water content in **Table 10** is for angular coarse aggregate and for 50 mm slump and may be adjusted after trials. The water content suggested in **Table 10** may be reduced by approximately 10 kg for sub-angular aggregates, 15 kg for gravel with some crushed particles and 20 kg for rounded gravel to produce same workability. For the desired workability (other than 50 mm slump range), the required water

content may be established by trial or an increase by about 3 per cent for every additional 25 mm slumps or alternatively by use of chemical admixture conforming to IS:9103. This illustrates the need for trial batch testing of local materials as each aggregate source is different and can influence concrete properties differently. Water reducing admixture or super plasticizing admixtures usually decrease water content by 5 to 10 per cent and by 20 per cent and above respectively at appropriate dosages.

Table 10 Approximate Water Content per Cubic Metre of Concrete for Nominal Maximum Size of Aggregate (without Plasticiser/Superplasticiser)

Nominal Maximum Size of Aggregate mm	Suggestive Water Content kg/m^3
9.5	208
19	186
31.5	165

These quantities of mixing water shall be used in computing cement/cementitious material contents for trial mixes.

On account of long distances over which concrete needs to be carried from batching plant/RMC plant, the concrete mix is generally designed for a higher slump initially than the slump required at the time of placing. The initial slump value shall depend on the distance of transport and loss of slump with time.

4.4.4 *Calculation of cement/cementitious material content*

The cement and supplementary cementitious material content per unit volume of concrete may be calculated from the free water-cement ratio (*see para* **4.4.2**) and the quantity of water per unit volume of concrete.

In certain situations, while using part replacement of cement by flyash, GGBFS, silica fume and metakaoline increase in cementitious material content may be warranted, particularly if flyash is 20 per cent or more and GGBFS is 30 per cent or more. The decision on increase in cementitious material content and its percentage may be based on experience and trials or the cementitious content so calculated may be increased by 10 per cent for preliminary trial.

The cement/cementitious material content so calculated shall be checked against the minimum and maximum cement/cementitious material content requirements. In case cement/ cementitious material content worked out is lower than the stipulated minimum cement/ cementitious material content, the greater of the two values shall be adopted.

The minimum cement/cementitious material content shall be 360 kg/m^3 and maximum cement content not including mineral admixtures shall be 450 kg/m^3 except when mentioned otherwise in the applicable specifications. For high strength concrete higher cement content may be considered as per the requirement of mix design.

In case fly ash (as per IS:3812- Part 1) is blended at site, the quantity of fly ash shall be restricted to 25 per cent by weight of cementitious material content and the quantity of OPC in such a blend shall not be less than 310 kg/m³. In case of GGBFS, minimum cement content shall be 250 kg. If this minimum OPC content is not sufficient to produce concrete of the specified strength, it shall be increased as necessary.

4.4.5 *Estimation of coarse and fine aggregate contents*

4.4.5.1 Estimation of coarse aggregate proportion in total aggregate

Aggregates of essentially the same nominal maximum size, type and grading will produce concrete of satisfactory workability when a given volume of coarse aggregate is used per unit volume of concrete. Approximate values for this aggregate volume are given in **Table 11** for a water-cement ratio of 0.50, which may be suitably adjusted for other water-cement ratios. The values so obtained shall be checked for combined grading to ensure that overall grading falls within the limits of **Table 3**. If not, suitable adjustment in the volumes of coarse and fine aggregate may be made. The proportion of volume of coarse aggregates is increased at the rate of 0.01 m³ for every decrease in water-cement ratio by 0.05 and decreased at the rate of 0.01 m³ for every increase in water-cement ratio by 0.05. It can be seen that for equal workability, the volume of coarse aggregate in a unit volume of concrete is dependent only on its nominal maximum size and grading zone of fine aggregate. Differences in the amount of mortar required for workability with different aggregates, due to differences in particle shape and grading, can be adjusted by changing coarse to fine aggregate ratios. Generally higher fine aggregate content is required for crushed angular coarse aggregates due to increased surface area.

For more workable concrete mixes which is sometimes required when placement is by pump, it may be desirable to reduce the estimated coarse aggregate content determined using **Table 11** up to 10 per cent.

Volumes are based on aggregates in saturated surface dry condition for angular aggregate and suitable adjustments may be made for other shapes of aggregate.

Table 11 Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate as per IS:383

Nominal Maximum Size of Aggregate mm	Volume of Coarse Aggregate Per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate		
	Zone III	Zone II	Zone I
9.5	0.48	0.46	0.44
19	0.64	0.62	0.60
26.5	0.69	0.67	0.65
31.5	0.68	0.65	0.63

4.4.5.2 Estimation of coarse and fine aggregate contents

With the completion of procedure given in **paras 4.4.3** and **4.4.4**, all the ingredients have been estimated except the coarse and fine aggregate content. These quantities are determined by finding out the absolute volume of cementitious material, water and the chemical admixture; by dividing their mass by their respective specific gravity, multiplying by 1/1000 and subtracting the result of their summation from unit volume. The values so obtained are divided into coarse and fine aggregate fractions by volume in accordance with coarse aggregate proportion already determined in **para 4.4.5.1**. The coarse and fine aggregate contents are then determined by multiplying absolute volume with their respective specific gravities and multiplying by 1000.

4.4.5.3 Check for combined grading of fine & coarse aggregate

It is recommended to achieve the combined grading of fine and coarse aggregates as per **Table 3**. Graded coarse aggregates or single-sized coarse aggregates of nominal size shall be mixed in suitable proportions with fine aggregate and/or the volumes of coarse and fine aggregates shall be adjusted suitably to achieve the combined grading requirement of **Table 3.**

4.5 Trial Mixes

4.5.1 *The calculated mix proportions shall be checked by means of trial batches*

Workability of the Trial Mix No. 1 shall be measured. The mix shall be carefully observed for freedom from segregation and bleeding and its finishing properties. If the measured workability of Trial Mix No. 1 is different from the stipulated value, the water and/or admixture content shall be adjusted suitably. With this adjustment, the mix proportion shall be recalculated keeping the free water cement ratio at the pre-selected value, which will comprise Trial Mix No. 2. In addition two more Trial Mixes No. 3 and 4 shall be made with the water content same as Trial Mix No. 2 and varying the free water-cement ratio by ± 10 per cent of the preselected value.

Mix No. 2 to 4 normally provides sufficient information, including the relationship between compressive strength and water-cement ratio, from which the mix proportions for field trails may be arrived at. The concrete for field trials shall be produced by methods of actual concrete production.

For the recommended mix proportions, the yield of the mix shall be checked and the mix proportions shall be adjusted proportionately to meet the requirement of yield of 1 m^3 of concrete.

4.5.2 Early prediction of 28 days compressive strength results as per IS:9013-1978 may be adopted for interim recommendation of mix design for concrete upto M60 grade made using OPC and normal superplasticiser. However, the production of concrete before actual 28 days results of trial mixes shall be done on the lower w/c ratio by 0.02 in the above recommendation. For concrete M65 and above, the recommendation shall only be based on 28 days compressive strength results.

5 APPROACH TO MIX PROPORTIONING FOR HIGH STRENGTH CONCRETE (GRADE M65 & ABOVE)

5.1 Introduction

High Strength Concrete is defined as the concrete that has characteristic compressive strength of 65 N/mm^2 or more. This part provides the guidance for selecting mix proportion for M 65 or above.

Usually, for high strength concrete mixes specially selected cementitious material and chemical admixtures i.e. super plasticizers are used, and achieving a low water – cementitious material ratio (w/cm) is considered essential.

The procedure for proportioning high strength concrete is similar to that required for ordinary/ standard strength concrete. The procedure consists of series of steps that, when completed, provide a mixture meeting workability, strength and durability requirements based on the combined properties of the individually selected and proportioned ingredients.

5.2 Concrete Material

Material shall be selected, proportioned & controlled carefully to achieve effective production of high strength concrete. The optimum proportions should be selected, considering the cement & other cementitious material properties, aggregate quality, aggregate gradation, paste volume, admixture type and dosage rate and mixing.

5.2.1 *Cementitious material*

Proper selection of type of cement is very important step for the production of high strength concrete. Flyash, Silica fume, GGBFS or Metakaoline are widely used as a cementitious and pozzolanic ingredient in high Strength Concrete.

5.2.2 *Coarse aggregate*

In the proportioning of high strength concrete, the aggregates require special consideration and they greatly influence the strength and other properties of concrete. Therefore, the coarse aggregate should be strong, sufficiently sound, free of fissures or weak planes, clean and free of surface coating & shall meet the requirement of IS:383.

5.2.3 *Fine aggregate*

The fine aggregates shall meet the requirements of IS:383. Generally, for high strength, a fine aggregate of coarser size is preferred i.e. Zone I or Zone II Sand because of high fines contents available from the cementitious materials.

5.2.4 *Chemical admixtures*

High Strength Concrete mixes generally have a low-cementitious material ratio (w/cm). These low w/cm ratios are only attainable with **High – range water-reducing admixtures (HRWRAS)** which also help in dispersing cement particles. HRWRAS which can reduce

mixing water requirement by more than 30 per cent, thereby increasing concrete compressive strength shall be used for high strength concrete.

5.3 Concrete Mix Proportioning

5.3.1 *Target strength for mix proportioning*

Please refer to **para 4.2**

5.3.2 *Select maximum size of coarse aggregate*

Based on strength requirement, the suggested maximum sizes for coarse aggregate is given in **Table 12**.

Table 12 Suggested Maximum-Size of Coarse Aggregate

<table>
<tr><th>Grade of Concrete</th><th>Suggested Maximum-Size of Coarse Aggregate, mm</th></tr>
<tr><td>M 65</td><td rowspan="3">19.0</td></tr>
<tr><td>M 70</td></tr>
<tr><td>M 75</td></tr>
<tr><td>M 80 & above</td><td>9.5 or 12.5</td></tr>
</table>

5.3.3 *Estimation of air content*

Approximate amount of entrapped air to be expected in normal (non-air-entrained) concrete is given in **Table 13**.

Table 13 Approximate Air Content

Nominal Maximum Size of Aggregate, mm	Entrapped Air, as Percentage of Volume of Concrete
9.5	1.0
12.5	0.7
19	0.5

5.3.4 *Estimate of mixing water*

The trial batching is the most effective way to determine the best proportions for the ingredients to be used. The water content in the chemical admixture (high range water reducing agents, HRWRA) shall be calculated to be a part of the w/cm ratio. **Table 14** gives estimates of maximum mixing water for high strength concrete. The water content is for 50 mm slump. For the desired workability (other than 50 mm slump), the required water content may be increased or decreased by about 3 per cent for each increase or decrease of 25 mm slump or may be established by trial. These quantities of mixing water are maximum for well shaped, clean, angular and well graded coarse aggregates. Since the particle shape and surface texture of fine aggregate can significantly influence the mixing water demand, the water requirement may be different from the values given in **Table 14** and shall be established by trials.

Table 14 Estimate of Maximum Mixing Water (without admixture)

Sl. No.	Nominal Maximum Size of Aggregate (mm)	Maximum Water Content (kg/m^3)
1	9.5	196
2	12.5	190
3	19.0	180

Water content mentioned above corresponding to saturated surface dry aggregate. These quantities of mixing water are for use in computing cement/cementitious material content for trial mixes. On account of long distances over which concrete needs to be carried from batching plant/RMC plant, the concrete mix is generally designed for a higher slump initially than the slump required at the time of placing. The initial slump value shall depend on the distance of transport and loss of slump with time.

5.3.5 *Selection of water – cementitious material ratio (w/cm)*

The w/cm ratio is calculated by dividing the mass of the mixing water by the combined mass of the cement and flyash (and other cementitious materials). In **Table 15**, recommended maximum w/cm ratio is given as a function of maximum – size aggregates to achieve different compressive strength at 28 days. The use of an HRWRA generally increases the compressive strength of concrete. The w/cm values given in **Table 15** are for concrete made with HRWRA.

Table 15 Recommended w/cm for High Strength Concrete made with High Range Water-Reducing Admixtures

Compressive Strength at 28 days (N/mm^2)	w/cm		
	Nominal Maximum Size of Aggregate (mm)		
	9.5 mm	12.5 mm	19 mm
65	0.36	0.35	0.33
70	0.34	0.33	0.31
75	0.32	0.31	0.29
80	0.30	0.29	0.27
85	0.28	0.27	0.26
90	0.26	0.25	0.24

5.3.6 *Calculate cementitious material content*

The cement and supplementary cementitious material content per unit volume of concrete may be calculated from the quantity of water **(para 5.3.4)** and the free water-cementitious materials ratio **(para 5.3.5)** per unit volume of concrete. However, this must satisfy the specification of maximum or minimum limit on the amount of cementitious material as per IRC:15.

If cement content (not including fly ash and ground granulated blast furnace slag) more than the maximum cement content as given in IRC:15 is to be used, it shall be ensured that the

special consideration has been given in design to the increased risk of cracking due to drying shrinkage, or to early thermal cracking and to the increased risk of damage due to alkali silica reactions.

The recommended dosages of different pozzolanic materials for high strength mixes are given in **Table 16**.

Table 16 Dosages of Different Pozzolanic Materials for High Strength Concrete

Flyash	15 - 25%
Ground Granulated Blast Furnace Slag	25 - 50%
Silica Fume	5 - 10%

5.3.7 *Estimation of coarse aggregate proportion*

The optimum content of the coarse aggregate depends on its strength and maximum nominal size of coarse aggregate. For proportioning of ordinary and standard grades of concrete, the optimum volume of coarse aggregate is given as a function of the maximum size of coarse aggregate and grading zone of fine aggregate. However, high strength grades of concrete are not dependent on the fine aggregate to provide fines for lubrication and consolidation of the fresh concrete as the mixes have high content of cementitious material. The recommended coarse aggregate volume per Unit Volume of total Aggregate for Different Zones of Fine Aggregate is given in **Table 17**.

Table 17 Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate for Water-Cement/Water-Cementitious Material Ratio of 0.30

Sl. No.	Nominal Maximum Size of Aggregate (mm)	Volume of Coarse Aggregate per Unit Volume of total Aggregate for Different Zones of Fine Aggregate		
		Zone III	Zone II	Zone I
1	9.5	0.67	0.65	0.63
2	12.5	0.69	0.67	0.65
3	19	0.72	0.70	0.68

Volumes are based on aggregates in saturated surface dry condition. These volumes are for Crushed (angular) aggregate and suitable adjustments may be made for other shape of aggregate. The above table is valid for w/cm material ratio of 0.30. For every decrease of 0.05 in w/cm ratio, the above ratio (volume of coarse aggregates) will be increased approximately by 0.01 & for every increase of 0.05 in w/cm ratio, the above ratio (volume of coarse aggregates) will be decreased approximately by 0.01.

5.3.8 *Estimation of fine and coarse aggregate contents*

With the completion of procedure given in **paras 5.3.4** and **5.3.5**, all the ingredients have been estimated except the coarse and fine aggregate content. These quantities are determined by finding out the absolute volume of cementitious material, water and the

chemical admixture; by dividing their mass by their respective specific gravity, multiplying by 1/1000 and subtracting the result of their summation from unit volume. The values so obtained are divided into coarse and fine aggregate fractions by volume in accordance with coarse aggregate proportion already determined in **para 5.3.7**. The coarse and fine aggregate contents are then determined by multiplying with their respective specific gravities and multiplying by 1000.

5.3.9 *Trial mixes*

The calculated mix proportions shall be checked by means of trial mixes. Workability of the Trial Mix No. 1 shall be measured. The mix shall be carefully observed for freedom from segregation and bleeding and its finishing properties. If the measured workability of Trial Mix No. 1 is different from the stipulated value, the water and/or admixture content shall be adjusted suitably. With this adjustment, the mix proportion shall be recalculated keeping the free water-cement ratio at the pre-selected value, which will comprise Trial Mix No. 2. In additional two more Trial Mixes No. 3 and 4 shall be made with the water content same as Trial Mix No. 2 and varying the free water-cement ratio by ±10 per cent of the preselected value.

Mix No. 2 to 4 normally provides sufficient information, including the relationship between compressive strength and water-cementitious materials ratio, from which the mix proportions can be finalized. Additional field trials are recommended particularly for workability requirements. The concrete for field trials shall be produced by methods of actual concrete production.

6 PERVIOUS CONCRETE

6.1 Introduction

The term pervious concrete typically describes a zero slump, open graded material consisting of Portland cement, coarse aggregate, little or no fine aggregate, admixture and water. The combination of these ingredients will produce a hardened material with connected pores that allow water to pass through easily. The void content can range from 15-35% with typical compressive strength of 5 MPa to 25 MPa. The drainage rate of pervious concrete pavement will vary with aggregate size and density of the mixture and will generally fall in the range of 0.135 to 1.22 cm/sec. Higher the fine content lesser will be the void contents and permeability. The concrete with low void contents are prone to clogging by water containing soil particles.

6.2 Materials

Pervious concrete is composed of cement or a combination of cement, coarse aggregate, and water. A small amount of fine aggregate may be incorporated to increase compressive strength. All materials should conform to the appropriate IS Specifications. A combination of cementitious materials that each conform to the appropriate IS Specifications can be used. Chemical admixtures are commonly used to improve various characteristics of pervious concrete. They should meet the appropriate IS Specifications or other Specifications that produce an acceptable mixture.

6.3 Mix Proportioning

6.3.1 *Data for mix proportioning*

The following data are required for mix proportioning of a particular grade of pervious concrete:

a) Grade designation (required compressive strength)
b) Range of water permeability
c) Type of cement
d) Maximum nominal size of aggregate
e) Whether a chemical admixture shall or shall not be used and the type of chemical admixture and the extent of use.
f) Whether a mineral admixture shall or shall not to be used and the type of mineral admixture and the extent of use.

6.3.2 *Target strength for mix proportioning*

In order that not more than the specified proportions of test results are likely to fall below the characteristic strength, the concrete mix has to be proportioned for higher target mean compressive strength (f'_{ck}). The margin over characteristic compressive strength is given by the following relation:

$$f'_{ck} = f_{ck} + 1.65 \times S_c$$

where

f'_{ck} = target mean compressive strength at 28 days, N/mm^2

f_{ck} = characteristic compressive strength at 28 days, N/mm^2

S_c = standard deviation of compressive strength, N/mm^2

6.3.2.1 *Assumed standard deviation*

Where sufficient test results for a particular grade of concrete are not available the value of standard deviation given in **Table 18** for mix designs based on compressive strength may be assumed for proportioning of mix.

Table 18 Assumed Standard Deviation Values for mix designs based on compressive strength (considering good quality control)

Sl. No.	Grade of concrete	Assumed Standard Deviation N/mm^2
1	M 10	2.5
2	M 15	3.0
3	M 20	4.0

6.3.3 *Selection of water- cementitious materials ratio*

The water-cementitious material ratio (w/cm) is an important consideration for obtaining desired strength and void structure in pervious concrete. A high w/cm reduces the adhesion of the paste to the aggregate and causes the paste to flow and fill the voids even when lightly compacted. A low w/cm will prevent good mixing and tend to cause balling in the mixer, prevent an even distribution of cement paste, and therefore reduce the ultimate strength and durability of the concrete. Experience has shown that w/cm in the range of 0.26 to 0.45 will provide the best aggregate coating and paste stability. The conventional w/cm-versus-compressive strength relationship for normal concrete does not apply to pervious concrete. Careful control of aggregate moisture and w/cm is important to produce consistent pervious concrete.

6.3.4 *Void content*

6.3.4.1 To ensure the water will percolate through pervious concrete, the void content should be 15 per cent or greater, as given in **Table 19**. If void content is lower than that of 15 per cent, there is no significant percolation thought the concrete and there is not sufficient interconnectivity between the voids to allow for rapid percolation.

Higher the void content, higher is the percolation rate and lower is the compressive strength. The lower the void content, lower is the percolation rate and higher the compressive strength. The compressive strength increases as the nominal maximum-size aggregate decreases. Compressive strength of pervious concrete is also a function of the aggregate strength, paste bonding characteristics, and strength of the cement paste itself. Some caution should be used when applying these quantitative numbers to practical design, as standardize methods do not yet exist for these properties of pervious concrete; prior discussion should be taken as purely qualitative.

6.3.4.2 The void content present in pervious concrete can be calculated by using the following mathematical procedure:

Total voids in coarse aggregate =

$$\frac{(\text{Absolute density of coarse aggregate} - \text{Dry rodded bulk density of coarse aggregate})}{\text{Absolute density of coarse aggregate}} \times 100$$

Theoretical porosity adopted for mix design	=	Total voids in coarse aggregate system – absolute volume of mortar constituents
Where, absolute volume of mortar constituents	=	Absolute volume of cement, water and fine aggregate if any

Table 19 Estimation of Approximate Void Content for Different Rates of Percolation (Percolation Rate as Measured by Permeability Test Method Given in Annexure-A)

Percolation (mm/min)	Void content, per cent by volume
50	15
150	20
350	25
1000	30
2250	35

Table 20 Estimation of Approximate Void Content for Different Strength of Pervious Concrete

Compressive Strength (Mpa)		Void content, per cent by volume
19 mm MSA	9.5 mm MSA	
5	8	30
10	12	25
15	18	20
20	23	15

6.3.5 *Estimation of paste volume (Vp), cement (c), and water content (w)*

The proportioning of pervious concrete seeks to establish the minimum volume of paste necessary to bind aggregate particles together, while maintaining the necessary void structure, strength, and **Table 21** can be used to estimate the volume of the paste for a mixture using maximum size of aggregate 9.5 mm.

Table 21 Estimation of Paste Content Using Void Content Value for MSA 9.5 mm Aggregate

Void content, per cent by volume	Paste volume, per cent by volume	
	for well compacted pervious concrete	for lightly compacted pervious concrete
15	18	25
20	15	22
25	10	17
30	5	14

The above value of paste volume is for the mixes having no fine aggregate. When the fine aggregate is used, the paste volume should be reduced by 2 per cent for each 10 per cent fine aggregate of the total aggregate for well compacted pervious concrete and by 1 per cent for each 10 per cent fine aggregate of the total aggregate for lightly compacted pervious concrete. These reductions are necessary to maintain the same per cent voids by volume.

Once the paste volume is determined from **Table 21**, and the w/cm selected, the cement and water quantities can be determined from the following absolute volume relationships:

Paste volume Vp = cement volume + water volume

$Vp = c/(3.15\text{x}1000\ \text{kg/m}^3)+w/1000\ \text{kg/m}^3$

Substituting $w=(w/cm)c$,

$Vp = c/(3.15\text{x}1000\ \text{kg/m}^3)+[(w/cm)c/1000\ \text{kg/m}^3]$

c can be determined quickly by trial and error on spreadsheet or algebraically reduced to

$$c = [(Vp/(0.315+w/cm)]\ \text{x}1000\ \text{kg/m}^3 \quad (1)$$

Therefore, once the paste volume is determined from **Table 21**, and the *w/cm* is selected, the mass of cement can be calculated from Eq. (1). From the mass of cement, the water content can be computed.

6.3.6 *Estimation of coarse aggregate proportion*

With the completion of procedure given in **para 6.3.3**, all the ingredients have been estimated except the coarse aggregate content. The absolute volume of pervious concrete shall be determined by subtracting the volume of voids from the unit volume. The volume of cementitious material, water and the chemical admixture shall be determined by dividing their mass by their respective specific gravity and multiplying by 1/1000. The volume of aggregate shall be determined by subtracting the volume of cementitious material, water and chemical admixture from the absolute volume of pervious concrete. The value so obtained is then multiplied by specific gravity of coarse aggregate and multiplied by 1000 to obtain the mass of coarse aggregate.

6.3.7 *Trial mixes*

Minimum three trials shall be conducted with paste content determined as above and ± 10 per cent paste content. Cylinder specimens of size 100 mm x 200 mm or 150 mm x 300 mm (3 for each trials) shall be cast for permeability testing (as per procedure given in **Annexure A**) and concrete cubes of size 150 mm x 150 mm x 150 mm shall be cast for compressive strength (to be tested as per procedure similar to IS:516). Testing to be done after 7-Day/28-Day water curing as per specifications.

6.3.8 *Water permeability test*

The testing method for measuring water permeability of pervious concrete is given in **Annexure A.**

7 EXAMPLES

The illustrative examples of concrete mix proportioning for conventional concrete pavement is given in **Annexure B** and **C** for mix design based on flexural strength of concrete for 4.5N/mm^2 flexural strength with and without flyash and M40 grade of concrete respectively. Another illustrative example of M60 grade of concrete for special applications, using silica fume is given in **Annexure D**. The mix proportioning of pervious concrete using no fine aggregate and using fine aggregate is given in **Annexure E** and **F** respectively. These examples are merely illustrative to explain the procedure and the actual mix proportioning shall be based on trial batches with the given materials.

The quantities of coarse and fine aggregates are based on aggregates in saturated surface dry conditions.

To determine the mix proportion based on aggregate in dry condition, the following procedure shall be adopted:

i) The quantities of both coarse and fine aggregates shall be divided by 1 plus their respective water absorptions.

ii) The values thus determined shall be the mass of aggregate content in dry condition.

iii) The water content shall be increased by an amount equal to the difference of mass of aggregate in Saturated Surface Dry (SSD) condition and dry condition.

To determine the mix proportion based on aggregate in wet condition, the following procedure shall be adopted:

i) Determine the total moisture content of fine aggregate and coarse aggregate.

ii) The quantities of both coarse and fine aggregates in Saturated Surface Dry (SSD) condition shall be divided by 1 plus their respective water absorptions. This will give the dry mass of the aggregates.

iii) Multiply the dry mass so obtained by 1 plus total moisture content. The value so obtained will be the mass of wet aggregate i.e. sum of mass of aggregate in SSD condition and surface moisture present in aggregate.

iv) The mass of surface moisture = Mass of Aggregate in wet condition – Mass of Aggregate in SSD condition.

v) The water content shall be reduced by an amount equal to the mass of surface moisture present in aggregate.

ANNEXURE A

TESTING METHOD FOR MEASURING PERMEABILITY OF PERVIOUS CONCRETE

A1 PRINCIPLE

The test specimens are pre-wetted before the first test. A given amount of water is poured into the specimen and the time for the water to infiltrate is measured.

A2 APPARATUS

A2.1 Apparatus for Testing Infiltration Rate

A2.1.1 Water Container – A cylindrical container typically made of plastic having a volume of at least 2000 ml, and from which water may be easily poured at a controlled rate into the funnel.

A2.1.2 Funnel – Watertight and sufficiently right to frame (see **Fig. 1**). The funnel shall have a capacity of 200 ml.

A2.1.3 Shrink Wrap – Heat shrink plastic film (polymer plastic film). Shrink wrap shall be made of non-absorbent material which does not react with cement paste.

A2.1.4 Stopwatch or Clock – Accurate to 0, 1 s.

A2.1.5 Water – Potable water.

A2.1.6 Heat Gun – Air heating system to fully wrap the specimens by heating the shrink wrap.

A3 SAMPLING

The test shall be performed with a minimum of three similar specimens. The specimens shall be made based on the specifications applicable to the project and area of construction.

A4 PROCEDURE

A4.1 Making the test specimen in the laboratory – A test specimen shall have a minimum diameter of 100 mm. There are two options for preparing the specimen, one with the specimen having a vertical porosity distribution representative of a field placement, and one with a more even porosity in the vertical direction.

A4.1.1 For the test specimen with a typical porosity distribution, the concrete shall be poured in one lift and consolidated with a rod by rammer. After consolidation is complete, the side of the mould is lightly tapped with a wooden or plastic hammer to remove foam generated by the compaction rod.

A4.1.2 For the test specimen with a more even porosity in the vertical direction, the concrete shall be poured in lifts and consolidated with a rod by rammer after each lift. For specimens with a diameter of 100 mm and height of 200 mm, there shall be three lifts. After consolidation is complete, the side of the mould is lightly tapped with a wooden or plastic hammer to remove foam generated by the compaction rod.

A4.1.3 The specimens shall be immediately covered after consolidation.

A4.1.4 **Curing –** The specimens shall remain in the covered mould and the mould shall be removed after a minimum curing period of 7 days.

A4.2 **Obtaining test specimen from the field** – Cut cores the full depth of the pervious concrete slab. Cores area a minimum 100 mm in diameter:

A4.3 **Wrapping** – Wrap the specimen with three layers of shrink wrap and tape the vertical seam full length. Trim the wrap even with the bottom of specimen and leave at least a 50 mm lip on the top to hold the minimal head.

A4.4 **Heating Shrink Wrap** – Heat the wrap with a heat gun to tighten the wrap on the vertical surface of the sample. This should prevent the flow of water between the wrap and the exterior of the sample. Do not heat the top 50 mm lip. The inner surface of the wrap shall be marked or scored with two lines at a distance of 15 mm and 25 mm from the top of the sample.

A4.5 **Pre-wetting** – Place the specimen upright in the funnel to allow to freely flow out of the bottom. Pour water into the specimen at a rate sufficient to maintain a head between the two marked lines. Use a total of 1000 ml of water for 100 mm diameter specimens.

A4.6 Pour the water into the specimen at a rate sufficient to maintain a head between the two marked lines and until the measured amount of water has been used. Begin timing as soon as the water impacts the pervious concrete surface. Stop timing when free water is no longer present on the pervious surface. The test shall be started within 5 min after the completion of the pre-wetting. Record the amount of water (2000 ml for 100 mm diameter specimens) to the nearest 10 ml. Record the testing duration (t) to the nearest 0,1 s.

A5 CALCULATION

$$k = \frac{W}{At}$$

Where, K infiltration rate (mm/s)

W volume of infiltrated water (mm^3)

A cross-sectional area of specimen (mm^2)

t time required for measured volume of water to infiltrate the concrete (s)

A6 TEST REPORT

In the event of a report being prepared, the following information shall be included:

a) Identification of the sample
b) Identification of the specimen
c) Information whether specimens are made in the laboratory or received as a core from the field
d) Details on how the specimen was prepared and cured in the laboratory
e) Specimen dimensions and density (both designed and measured)
f) Age of specimen at test
g) Volume of water poured onto the specimen during test (mm^3)
h) Time required for the measured amount of water to infiltrate into the concrete (s)
i) Infiltration rate (mm/s)

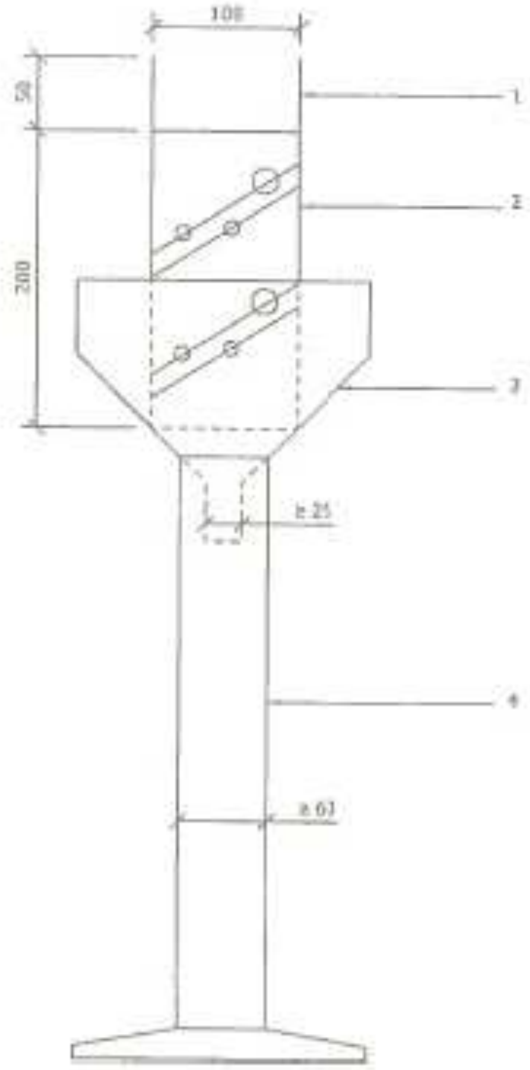

Fig 1: Test setup and Dimensions (all dimensions in mm)

Where:

1 Shrink wrap
2 Test specimen
3 Funnel
4 Graduated cylinder

ANNEXURE B

ILLUSTRATIVE EXAMPLE ON CONCRETE MIX PROPORTIONING BASED ON FLEXURAL STRENGTH

An example illustrating the mix proportioning for a concrete of 4.5 N/mm² Flexural Strength is given below:

B1 STIPULATIONS FOR PROPORTIONING

a) Grade designation	4.5 N/mm² Flexural Strength
b) Type of cement	OPC 43 grade conforming to IS:269
c) Maximum nominal size of aggregate	31.5 mm
d) Minimum cement content (as per IRC:15)	360 kg/m³
e) Maximum water-cement ratio (as per IRC:15)	0.40
f) Workability	25 ± 10 mm (slump)
g) Degree of supervision	Good
h) Type of aggregate	Crushed angular aggregate
i) Maximum cement content	450 kg/m³
j) Chemical admixture type	Superplasticizer

B2 TEST DATA FOR MATERIALS

a)	Cement used	OPC 43 grade conforming to IS:269
b)	Specific gravity 1) Cement 2) Coarse aggregate 3) Fine aggregate	 3.15 2.74 2.62
c)	Water absorption 1) Coarse aggregate 2) Fine aggregate	 0.5 per cent 1.0 per cent
d)	Free (surface) moisture 1) Coarse aggregate 2) Fine aggregate	Nil (absorbed moisture also nil) Nil (absorbed moisture also nil)

e)	Sieve analysis 1) Coarse aggregate	IS Sieve sizes mm	Analysis of Coarse Aggregate Fraction, % Passing		
			Fraction I 31.5 to 19 mm	Fraction II 19 to 9.5 mm	Fraction III 9.5 mm down
		31.5	100.0	100.0	100.0
		19	20.0	100.00	100.00
		9.5	4.8	2.80	78.30
		4.75	Nil	Nil	8.70
	2) Fine aggregate	Conforming to grading Zone II as per IS:383			

B3 DESIGN FLEXURAL STRENGTH FOR MIX PROPORTIONING

$f'_{cr} = f_{cr} + 1.65\ S_r$

or

$f'_{cr} = f_{cr} + 0.55$

Whichever is higher

Where

f'_{cr} = target mean flexural strength strength at 28 days,

f_{cr} = characteristic flexural strength at 28 days, and

S_r = standard deviation of flexural strength.

From **Table 5**, standard deviation, S_r = 0.40 N/mm^2.

Therefore, target strength using both equations i.e.

i) $f'_{cr} = f_{cr} + 1.65\ S_r$

$= 4.5 + 1.65 \times 0.40 = 5.16$ N/mm^2

ii) $f'_{cr} = f_{cr} + 0.45$

$= 4.5 + 0.55 = 5.05$ N/mm^2

The higher value is to be adopted. Therefore, target strength will be 5.16 N/mm^2 as 5.16 N/mm^2 > 5.05 N/mm^2.

B4 APPROXIMATE AIR CONTENT

From **Table 7**, the approximate amount of entrapped air to be expected in normal (non-air-entrained) concrete is 0.8 per cent for 31.5 mm nominal maximum size of aggregate.

B5 SELECTION OF WATER-CEMENT RATIO

From **Table 8**, the free water-cement ratio required for the target strength of 5.16 N/mm^2 is 0.32 (interpolated value) for OPC-43 grade. This is lower than the maximum value of 0.40.

0.32 < 0.40, hence O.K.

B6 SELECTION OF WATER CONTENT

From **Table 10**, water content for 31.5 mm aggregate = 165 kg/m^3 (for 50 mm slump)

Estimated water content for 25 mm slump = $165 - \frac{3}{100} \times 165$

= 160.05 say 160 kg/m^3

As super plasticizer is proposed to be used, a minimum of 20 per cent water content can be reduced (vide **para 4.4.3** for details). For the purpose of present trial exercise, a reduction of water content of 20 per cent has been assumed by adjusting suitably the doses of the super plasticizer. The designer can use this reduction as per his requirement of the availability of the grade of cement and quality of super plasticizer. With 20 per cent reduction in water content, the reduced water content equals to 160 x 0.80 = 128 kg

B7 CALCULATION OF CEMENT CONTENT

Water–cement ratio	=	0.32
Water content	=	128 kg/m^3
Cement content	=	128/0.32 = 400 kg/m^3

Check for minimum and maximum cement content as per IRC:15

Minimum cement content as per IRC:15, 360 kg/m^3 < 400 kg/m^3 Hence, O.K

Maximum cement content as per IRC:15, 450 kg/m^3 > 400 kg/m^3 Hence, O.K

B8 PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT

From **Table 11** Volume of coarse aggregate per unit volume of total aggregate corresponding to 31.5 mm size aggregate and fine aggregate grading Zone II = 0.65. This is valid for water-cement ratio of 0.50. As water-cement ratio is actually 0.32, the ratio is taken as $0.65 + \frac{(0.5 - 0.32) \times 0.01}{0.05}$ =0.686 to reduce sand content. (as per **para 4.4.5** and **Table 11**)

Volume of fine aggregate content = 1 – 0.686 = 0.314 per unit volume of total aggregate

B9 CHECK FOR COMBINED GRADING OF FINE & COARSE AGGREGATE: It is recommended to achieve the combined grading of fine and coarse aggregates as per **Table 3**. Graded coarse aggregates or single-sized coarse aggregates of nominal size shall be mixed in suitable proportions with fine aggregate and/or the volumes of coarse and fine aggregates shall be adjusted suitably to achieve the combined grading requirement of **Table 3.**

B10 MIX CALCULATIONS

a) Absolute Volume of concrete	= 1- volume of air = 1-0.008 = 0.992 m^3
b) Volume of cement	(Mass of cement/Specific gravity of cement) x (1/1000) = (400/3.15) x (1/1000) = 0.127 m^3

c)	Volume of water	(Mass of water/Specific gravity of water) x (1/1000) = (128/1) x (1/1000) = 0.128 m^3
d)	Volume of chemical admixture (superplasticizer) @ 1.0% by mass of cementitious material]	(Mass of chemical admixture/Specific gravity of admixture) x (1/1000) =(4.0/1.2) x (1/1000) = 0.0033 m^3
e)	Volume of all in aggregate	= { a - (b+c+d) } = 0.992-(0.127+0.128+0.0033) = 0.7337 m^3
f)	Mass of coarse aggregate	= (e) x volume of coarse aggregate x Specific gravity of coarse aggregate x 1000 = 0.7337 x 0.686 x 2.74 x 1000 = 1379 kg/m^3
g)	Mass of fine aggregate	= (e) x volume of fine aggregate x Specific gravity of fine aggregate x 1000 = 0.7337 x 0.314 x 2.62 x 1000 = 603.6 Say 604 kg/m^3

B10.1 Mix Proportions for Trial Number 1 Based on Aggregate in SSD Condition

Cement = 400 kg/m^3

Water = 128 kg/m^3

Fine Aggregate = 604 kg/m^3

Coarse Aggregate = 1379 kg/m^3

Chemical Admixture = 4.0 kg/m^3

Water-cement ratio = 0.32

B10.2 Mix Proportions for Trial Number 1 Based on Aggregate in Dry Condition

Cement = 400 kg/m^3

Water = 128 + 6.0* + 7.0** = 141 kg/m^3

Chemical Admixture = 4.0 kg/m^3

Fine Aggregate = Mass of fine aggregate in SSD condition/(1+water absorption/100) = 604/(1+ 1/100) = 604/1.01

= 598 kg/m^3

Coarse Aggregate = Mass of coarse aggregate in SSD condition/(1+water Absorption/100) = 1379/(1+ 0.5/100) = 1379/1.005

= 1372.1 say 1372 kg/m

*Extra water to be absorbed by dry fine aggregate = 604 – 598 = 6.0 kg/m^3

** Extra water to be absorbed by dry coarse aggregate = 1379 – 1372 = 7.0kg/m^3

B11 The slump shall be measured and the water content and dosage of admixture shall be adjusted for achieving the required slump based on trial, if required. The mix proportions shall be reworked for the actual water content and checked for durability requirements.

B12 Two more trials having variation of ± 10 per cent of water-cement ratio in C-10 shall be carried out and a graph between three water-cement ratios and their corresponding strengths shall be plotted to work out the mix proportions for the given target strength for field trials. However, minimum and maximum cement content requirements should be met.

B13 Adjustment due to higher slump requirements for use of RMC can be made as follows:

Based on initial trials, it has been established that for expected 1 hour transit time initial slump requirement is 100 mm for 25 mm slump at the time of placement.

Based on trials dosage of admixture may be increased to achieve required workability (accordingly all other calculations can be modified).

B14 IN CASE IT IS PROPOSED TO USE FLYASH IN THE CONCRETE

B14.1 Calculation of Cement and Fly Ash Contents

Water–cement ratio = 0.32

Cement content = 128/0.32 = 400 kg/m^3

Now, to proportion a mix containing fly ash the following steps are suggested:

i) Decide percentage fly ash to be used based on project requirement and quality of materials

ii) *Increase the cementitious material content by 10 per cent of total cementitious material content of control mix calculated as above, to account for fly ash reactivity.

Cementitious material content = 400 x 1.10 = 440 kg/m^3

* In certain situation increase in cementitious material content may be warranted. The decision on increased in cementitious material and its percentage may be based on experience and trial. This illustrative example is with increase of 10 per cent cementitious materials content.

Water Content = 128 kg/m^3

So, water-cementitious materials ratio = 128/440 = 0.29

Fly ash @ 20% of total cementitious content = 440 x 20% = 88 kg/m^3

Cement (OPC) = 440 - 88 = 352 kg/m^3

Check for maximum cement content

Maximum cement (OPC) content as per IRC:15, 450 kg/m^3 > 352 kg/m^3

Hence, OK

Check for minimum OPC content as per IRC:15, 310 kg/m^3 < 352 kg/m^3

Hence, OK

B14.2 Proportion of Volume of Coarse Aggregate and Fine Aggregate Content

From **Table 11**, Volume of coarse aggregate corresponding to 31.5 mm size aggregate and fine aggregate Zone II = 0.65 per unit volume of total aggregate. This is valid for water-cement ratio of 0.50. As water-cement ratio is actually 0.29, the ratio is taken as 0.692 to reduce sand content.

Volume of fine aggregate content = 1 – 0.692 = 0.308

B14.3 Mix Calculations

a)	Absolute Volume of concrete	= 1- volume of air = 1-0.008 = 0.992 m^3
b)	Volume of cement	(Mass of cement/Specific gravity of cement)x(1/1000) = (352/3.15) x 1/1000 = 0.1117 m^3
c)	Volume of fly ash	(Mass of fly ash/Specific gravity of fly ash) x 1/1000 = (88/2.2) x 1/1000 = 0.040 m^3
d)	Volume of water	(Mass of water/Specific gravity of water) x 1/1000 = (128/1) x 1/1000 = 0.128 m^3
e)	Volume of chemical admixture (superplasticizer) [@ 1.0% by Mass of cementitious material]	(Mass of chemical admixture/Specific gravity of admixture) x (1/1000) = (4.40/1.2) x 1/1000 = 0.0037 m^3
f)	Volume of all in aggregate	= {a-(b+c+d+e)} = 0.992-(0.1117+0.040+0.128+0.0037) = 0.7086 m^3
g)	Mass of coarse aggregate	= (f) x volume of coarse aggregate x Specific gravity of coarse aggregate x 1000 = 0.7086 x 0.692 x 2.74 x 1000 = 1343.5 Say 1344 kg/m^3
h)	Mass of fine aggregate	= (f) x volume of fine aggregate x Specific gravity of fine aggregate x 1000 = 0.7086 x 0.308 x 2.62 x 1000 = 571.8 Say 572 kg/m^3

B14.4.1 Mix Proportions for Trial Number 1 on Aggregate in (Saturated Surface Dry) SSD Condition

Cement = 352 kg/m^3

Fly Ash = 88 kg/m^3

Water = 128 kg/m^3

Fine Aggregate = 572 kg/m^3

Coarse Aggregate = 1344 kg/m^3

Chemical Admixture = 4.4 kg/m^3

Water-(Cement + Flyash ratio) = 0.29

B14.4.2 Mix Proportions for Trial Number 1 on Aggregate in Dry Condition

Cement = 352 kg/m^3
Fly Ash = 88 kg/m^3
Water = 128+6.0*+7.0**=141 kg

Fine Aggregate	= Mass of fine aggregate in SSD condition/(1+ water absorption/100) = 572/(1+ 1/100) = 572/1.01=566.3 say 566 kg/m^3
Coarse Aggregate	= Mass of coarse aggregate in SSD condition/(1+ water Absorption/100) = 1344/(1+ 0.5/100) = 1344/1.005 = 1337.3 say 1337 kg/m
Chemical Admixture	= 4.40 kg/m^3
Water-(Cement + Flyash ratio)	= 0.29

*Extra water to be absorbed by dry fine aggregate = 572–566 = 6.0 kg/m^3

** Extra water to be absorbed by dry coarse aggregate = 1344–1337=7.0 kg/m^3

All other steps will remain same as **B 11** to **B 13**.

ANNEXURE C

ILLUSTRATIVE EXAMPLE ON CONCRETE MIX PROPORTIONING BASED ON COMPRESSIVE STRENGTH

An example illustrating the mix proportioning for a concrete of M 40 grade is given below:

C1 STIPULATIONS FOR PROPORTIONING

a)	Grade designation	M 40
b)	Type of cement	OPC 43 grade conforming to IS:269
c)	Maximum nominal size of aggregate	19 mm
d)	Minimum cement content (as per IRC:15)	360 kg/m^3
e)	Maximum water-cement ratio (as per IRC:15)	0.40
f)	Workability	25 ± 10 mm (slump)
g)	Degree of supervision	Good
h)	Type of aggregate	Crushed angular aggregate
i)	Maximum cement content	450 kg/m^3
j)	Chemical admixture type	Superplasticizer

C2 TEST DATA FOR MATERIALS

a)	Cement used	OPC 43 grade conforming to IS:269
b)	Specific gravity 1) Cement 2) Coarse aggregate 3) Fine aggregate	 3.15 2.74 2.62
c)	Water absorption 1) Coarse aggregate 2) Fine aggregate	 0.5 per cent 1.0 per cent
d)	Free (surface moisture) 1) Coarse aggregate 2) Fine aggregate	Nil (absorbed moisture also nil) Free (surface) moisture is 4.0 per cent & absorbed moisture is 1.0 per cent. Therefore, total moisture in sand = 5.0 per cent

		IS Sieve sizes mm	Analysis of Coarse Aggregate Fraction, % Passing	
e)	Sieve analysis 1) Coarse aggregate		Fraction I 19 to 9.5 mm	Fraction II 9.5 mm down
		19	100.00	100.00
		9.5	2.80	78.30
		4.75	Nil	8.70
	2) Fine aggregate	Conforming to grading Zone II as per IS:383		

C3 DESIGN COMPRESSIVE STRENGTH FOR MIX PROPORTIONING

$f'_{ck} = f_{ck} + 1.65\ S_c$

or

$f'_{ck} = f_{ck} + X$

Whichever is higher

Where

f'_{ck} = target average compressive strength at 28 days,

f_{ck} = characteristic compressive strength at 28 days, and

S_c = standard deviation of compressive strength.

From **Table 6**, standard deviation, S_c = 5.0 N/mm^2.

Therefore, target strength using both equations i.e.

i) $f'_{ck} = f_{ck} + 1.65\ S_c$
$= 40 + 1.65 \times 5.0 = 48.25$ N/mm^2

ii) $f'_{ck} = f_{ck} + 6.5$ *(The value of X for M40 grade as per* **Table 4** *is 6.5 N/mm^2)*
$= 40 + 6.5 = 46.5$ N/mm^2

The higher value is to be adopted. Therefore, target strength will be 48.25 N/mm^2 as 48.25 N/mm^2 > 46.5 N/mm^2.

C4 APPROXIMATE AIR CONTENT

From **Table 7**, the approximate amount of entrapped air to be expected in normal (non-air-entrained) concrete is 1.0 per cent for 19 mm nominal maximum size of aggregate.

C5 SELECTION OF WATER-CEMENT RATIO

From **Table 9**, the free water-cement ratio required for the target strength of 48.25 N/mm^2 is 0.36 for OPC-43 grade. This is lower than the maximum value of 0.50.

0.36 < 0.40, hence O.K.

C6 SELECTION OF WATER CONTENT

From **Table 10**, water content for 19 mm aggregate = 186 kg/m^3 (for 50 mm slump)

Estimated water content for 25 mm slump = $186 - \frac{3}{100} \times 186$

= 180.4 say 180kg/m^3

As super plasticizer is proposed to be used, a minimum of 20 per cent water content can be reduced (vide **para 5.3** for details). For the purpose of present trial exercise, a reduction of water content of 20 per cent has been assumed by adjusting suitably the doses of the super plasticizer. The designer can use this reduction as per his requirement of the availability of the grade of cement and quality of super plasticizer. With 20 per cent reduction in water content at water-cement ratio of 0.38, the reduced water content equals to 180 x 0.80 = 144 kg

C7 CALCULATION OF CEMENT CONTENT

Water–cement ratio	= 0.36
Water content	= 144 kg/m^3
Cement content	= 144 / 0.36 = 400 kg/m^3

Check for minimum and maximum cement content as per IRC:15

Minimum cement content as per IRC:15, 360 kg/m^3 < 400 kg/m^3 Hence, O.K

Maximum cement content as per IRC:15, 450 kg/m^3 > 400 kg/m^3 Hence, O.K

C8 PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT

From **Table 11** Volume of coarse aggregate corresponding to 19 mm size aggregate and fine aggregate grading Zone II = 0.62. This is valid for water-cement ratio of 0.50. As water-cement ratio is actually 0.36, the ratio is taken as 0.648 to reduce sand content. (as per **para 4.4.5** and **Table 11**)

Volume of fine aggregate content = 1 – 0.648 = 0.352 per unit volume of total aggregate

C9 CHECK FOR COMBINED GRADING OF FINE & COARSE AGGREGATE

It is recommended to achieve the combined grading of fine and coarse aggregates as per **Table 3**. Graded coarse aggregates or single-sized coarse aggregates of nominal size shall be mixed in suitable proportions with fine aggregate and/or the volumes of coarse and fine aggregates shall be adjusted suitably to achieve the combined grading requirement of **Table 3**

C10 MIX CALCULATIONS

a) Absolute Volume of concrete	= 1- volume of air = 1-0.01 = 0.99 m^3
b) Volume of cement	(Mass of cement/Specific gravity of cement) x (1/1000) = (400/3.15) x (1/1000) = 0.127 m^3
c) Volume of water	(Mass of water/Specific gravity of water) x (1/1000) = (144/1) x (1/1000) = 0.144 m^3
d) Volume of chemical admixture (superplasticizer) [@ 1.0% by mass of cementitious material]	(Mass of chemical admixture/Specific gravity of admixture) x (1/1000) = (4.00/1.2) x (1/1000) = 0.003 m^3
e) Volume of all in aggregate	= { a - (b+c+d) } = 0.99-(0.127+0.144+0.003) = 0.716 m^3
f) Mass of coarse aggregate	= (e) x 0.648 x Specific gravity of coarse aggregate x 1000 = 0.716 x 0.648 x 2.74 x 1000 = 1271.3 Say 1271 kg/m^3
g) Mass of fine aggregate	= (e) x 0.352 x Specific gravity of fine aggregate x 1000 = 0.716 x 0.352 x 2.62 x 1000 = 660.3 Say 660 kg/m^3

C10.1 Mix Proportions for Trial Number 1 Based on Aggregate in SSD Condition

Cement = 400 kg/m^3

Water = 144 kg/m^3

Fine Aggregate = 660 kg/m^3

Coarse Aggregate = 1271 kg/m^3

Chemical Admixture = 4.0 kg/m^3

Water-cement ratio = 0.36

C10.2 Mix Proportions for Trial Number 1 Based on Fine Aggregate in Wet Condition and Coarse Aggregate in Dry Condition

Cement	= 400 kg/m^3
Water = 144 - 26.0* + 6.0**	= 124 kg/m^3
Chemical Admixture	= 4.00 kg/m^3
Fine Aggregate in wet condition	= 686 kg/m^3

Step I: Dry mass of fine aggregate	= mass of fine aggregate in SSD condition/ (1+water absorption/100) = 660/(1 + 1/100) = 660/1.01 = 653 kg/m^3
Step II: Mass of wet fine aggregate	= Dry mass of fine aggregate x (1 + total Moisture/100) = 653 x (1+5/100) = 653 x 1.05 = 685.6 say 686 kg/m^3
Step III: Surface Moisture	= Mass of fine aggregate in wet condition– Mass of fine aggregate in SSD condition = 686 – 660 = 26 kg/m^3
Coarse Aggregate in Dry condition	= Mass of coarse aggregate in SSD condition/(1+ water absorption/100) = 1271/(1+0.5/100) = 1271/1.005 = 1264.6 say 1265 kg/m^3

*Extra water present in wet fine aggregate = 686 – 660 = 26 kg/m^3

** Extra water to be absorbed by dry coarse aggregate = 1271 – 1265 = 6.0 kg/m^3

C11 The slump shall be measured and the water content and dosage of admixture shall be adjusted for achieving the required slump based on trial, if required. The mix proportions shall be reworked for the actual water content and checked for durability requirements.

C12 Two more trials having variation of ± 10 per cent of water-cement ratio in **C 10** shall be carried out and a graph between three water-cement ratios and their corresponding strengths shall be plotted to work out the mix proportions for the given target strength for field trials. However, minimum and maximum cement content requirements should be met.

C13 Adjustment due to higher slump requirements for use of RMC can be made as follows:

Based on initial trials, it has been established that for expected 1 hour transit time initial slump requirement is 100 mm for 25 mm slump at the time of placement.

Based on trials dosage of admixture may be increased to achieve required workability (accordingly all other calculations can be modified).

ANNEXURE D

ILLUSTRATIVE EXAMPLE ON CONCRETE MIX PROPORTIONING FOR HIGH STRENGTH CONCRETE (BASED ON COMPRESSIVE STRENGTH)

An example illustrating the mix proportioning for a concrete of M 65 grade using silica fume is given below. The silica fume (very fine non-crystalline silicon dioxide) is a by-product of the manufacture of silicon, ferrosilicon or the like, from quartz and carbon in electric arc furnace. It is usually used in proportion of 5 to 15 per cent of the cementitious material content of the mix. Use of silica fume is generally advantageous for higher grades of concrete i.e. M50 and above and for high performance concrete with special requirements e.g. higher abrasion resistance of concrete.

D1 STIPULATIONS FOR PROPORTIONING

a) Grade designation	M 65
b) Type of cement	OPC 53 grade conforming to IS:269
c) Silica fume	Conforming to IS:15388
d) Maximum nominal size of aggregate	19 mm
e) Minimum cement content	360 kg/m^3
f) Maximum water-cementitious materials ratio	0.40
g) Workability	25 ± 10 mm (slump)
h) Degree of supervision	Good
i) Type of aggregate	Crushed angular aggregate
j) Chemical admixture type	Superplasticizer (Polycarboxylate based)

D2 TEST DATA FOR MATERIALS

a)	Cement used	OPC 53 grade conforming to IS:269
b)	Specific gravity 1) Cement 2) Silica fume 3) Coarse aggregate 4) Fine aggregate	 3.15 2.20 2.74 2.62
c)	Water absorption 1) Coarse aggregate 2) Fine aggregate	 0.5 per cent 1.0 per cent
d)	Free (surface) moisture 1) Coarse aggregate 2) Fine aggregate	 Nil (absorbed moisture also nil) Nil (absorbed moisture also nil)

e)	Sieve analysis 1) Coarse aggregate	IS Sieve sizes mm	Analysis of Coarse Aggregate Fraction, % passing	
			Fraction I 19 to 9.5 mm	Fraction II 9.5 mm down
		19	100.00	100.00
		9.5	2.80	78.30
		4.75	Nil	8.70
	2) Fine aggregate	Conforming to grading Zone II of Table 2		

D3 DESIGN COMPRESSIVE STRENGTH FOR MIX PROPORTIONING

$f'_{ck} = f_{ck} + 1.65\ S_c$

or

$f'_{ck} = f_{ck} + X$

Whichever is higher

Where

f'_{ck} = target average compressive strength at 28 days,

f_{ck} = characteristic compressive strength at 28 days, and

S_c = standard deviation of compressive strength.

From **Table 6**, standard deviation, S_c = 6.0 N/mm^2.

Therefore, target strength using both equations i.e.

i) $f'_{ck} = f_{ck} + 1.65\ S_c$
$= 65 + 1.65 \times 6.0 = 74.9$ N/mm^2

ii) $f'_{ck} = f_{ck} + 8.0$ *(The value of X for M65 grade as per* **Table 4** *is 8.0 N/mm*^{2}*)*
$= 65 + 8.0 = 73.0$ N/mm^2

The higher value is to be adopted. Therefore, target strength will be 74.9 N/mm^2 as 74.9 N/mm^2 > 73.0 N/mm^2.

D4 APPROXIMATE AIR CONTENT

From **Table 13**, the approximate amount of entrapped air to be expected in normal (non-air-entrained) concrete is 0.5 per cent for 19.0 mm nominal maximum size of aggregate.

D5 SELECTION OF WATER-CEMENTIOUS MATERIALS RATIO

From **Table 15**, the free water-cementitious materials ratio required for the target strength of 74.9 N/mm^2 is 0.29 for MSA 19 mm. This is lower than the maximum value of 0.40.

0.29 < 0.40, hence O.K.

D6 SELECTION OF WATER CONTENT

From **Table 14**, water content for 19 mm aggregate = 180 kg/m^3 (for 50 mm slump)

Estimated water content for 25 mm slump = $180 - \frac{3}{100} \times 180$

= 174.6 say 175 kg/m^3

As superplasticizer (Polycarboxylate based) is used, the water content can be reduced by 30 per cent. Hence, the reduced water content = 175 x 0.70 = 122.5 say 123 kg/m^3

D7 CALCULATION OF CEMENT CONTENT

Water–cementitious ratio	= 0.29
Water content	= 123 kg/m^3
Cementitious content	= 123/0.29 = 424.1 say 424 kg/m^3
Silica fume @ 5% by weight of Cementitious Material	= 424 x 5% = 21.2 say 21 kg/m^3
Cement Content	= 424 – 21= 403 kg/m^3
Check for minimum cement content,	360 kg/m^3 < 403 kg/m^3 Hence, OK
Check for maximum cement content,	450 kg/m^3 > 403 kg/m^3 Hence, OK

D8 PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT

From **Table 17**, Volume of coarse aggregate corresponding to 19 mm size aggregate and fine aggregate grading Zone II = 0.70 per unit volume of total aggregate. This is valid for water-cement ratio of 0.30. As water-cement ratio is actually 0.29, the ratio is taken as 0.702 to reduce sand content.

Volume of fine aggregate content = 1 – 0.702 = 0.298 per unit volume of total aggregate

D9 MIX CALCULATIONS

a) Absolute Volume of concrete	= 1 – Volume of air = 1 – 0.005 = 0.995 m^3
b) Volume of cement	= (Mass of cement/Specific gravity of cement) x (1/1000) = (403/3.15) x 1/1000 = 0.128 m^3
c) Volume of silica fume	= (Mass of silica fume/Specific gravity of silica fume) x 1/1000 = (21/2.2) x 1/1000 = 0.010 m^3
d) Volume of water	= (Mass of water/Specific gravity of water) x 1/1000 = (123/1) x 1/1000 = 0.123 m^3

e)	Volume of chemical admixture (superplasticizer) [@ 0.8 by Mass of cementitious material]	= (Mass of chemical admixture/Specific gravity of admixture) x (1/1000) = (3.4/1.08) x 1/1000 = 0.003 m^3
f)	Volume of all in aggregate	= {a-(b+c+d+e)} = 0.995 - (0.128+0.010+0.123+0.003) = 0.731 m^3
g)	Mass of coarse aggregate	= (f) x volume of coarse aggregate x Specific gravity of coarse aggregate x 1000 = 0.731 x 0.702 x 2.74 x 1000 = 1406 kg/m^3
h)	Mass of fine aggregate	= (f) x volume of fine aggregate x Specific gravity of fine aggregate x 1000 = 0.731 x 0.298 x 2.62 x 1000 = 570.7 Say 571 kg/m^3

D9.1 Mix Proportions for Trial Number 1 on Aggregate in SSD Condition

Cement = 403 kg/m^3
Silica fume = 21 kg/m^3
Water = 123 kg/m^3
Fine Aggregate = 571 kg/m^3
Coarse Aggregate = 1406 kg/m^3
Chemical Admixture = 3.40 kg/m^3

Water-(Cement + Silica Fume ratio) = 0.29

D9.2 Mix Proportions for Trial Number 1 on Aggregate in Dry Condition

Cement = 403 kg/m^3
Silica fume = 21 kg/m^3
Water = 123+6.0*+7.0**=136 kg

Fine Aggregate	= Mass of fine aggregate in SSD condition/(1+ water absorption/100) = 571/(1+ 1/100) = 571/1.01=565.3 say 565 kg/m^3
Coarse Aggregate	= Mass of coarse aggregate in SSD condition/(1+ water Absorption/100) = 1406/(1+ 0.5/100) = 1406/1.005 = 1399 kg/m^3
Chemical Admixture	= 3.40 kg/m^3
Water-(Cement + silica fume ratio)	= 0.29

*Extra water to be absorbed by dry fine aggregate = 575 – 569 = 6.0 kg/m^3

** Extra water to be absorbed by dry coarse aggregate = 1416 – 1409 = 7.0 kg/m^3

All other steps will remain same as **C 10** to **C 12**.

ANNEXURE E

ILLUSTRATIVE EXAMPLE ON PERVIOUS CONCRETE MIX PROPORTIONING

An example illustrating the mix proportioning for pervious concrete of M10 grade having minimum percolation rate of 350 mm/min using no fine aggregate.

E1 STIPULATIONS FOR PROPORTIONING

a) Grade designation	M10
b) Type of cement	OPC 43 grade conforming to IS:269
c) Maximum nominal size of aggregate	9.5 mm
d) Minimum percolation rate	350 mm/min

E2 TEST DATA FOR MATERIALS

a)	Cement used	OPC 43 grade conforming to IS:269
b)	Specific gravity 1) Cement 2) Coarse aggregate	 3.15 2.70
c)	Water absorption 1) Coarse aggregate	 0.5 per cent
d)	Free (surface) moisture 1) Coarse aggregate	 Nil (absorbed moisture also nil)

E3 DESIGN COMPRESSIVE STRENGTH FOR MIX PROPORTIONING

$f'_{ck} = f_{ck} + 1.65\ S$

Where

f'_{ck} = target mean compressive strength at 28 days,

f_{ck} = characteristic compressive strength at 28 days, and

S = standard deviation of compressive strength.

From **Table 18**, standard deviation, S = 2.5 N/mm^2.

Therefore, target strength,

$f'_{ck} = f_{ck} + 1.65\ S$

$= 10 + 1.65 \times 2.5 = 14.13$ N/mm^2

E4 SELECTION OF WATER-CEMENT RATIO

The conventional water cement ratio v/s compressive strength relationship for normal concrete does not apply to pervious concrete.

Let us take water cement ratio = 0.38 for the first trial.

E5 VOID CONTENT

From **Table 19**, void content = 25% for percolation rate of 350 mm/min

From **Table 20**, void content = 23% for compressive strength of 14.13 N/mm^2

Let us take an average value of 24% to satisfy the requirement of percolation rate and compressive strength.

E6 PASTE VOLUME (Vp), CEMENT CONTENT (c) AND WATER CONTENT (w)

From **Table 21**, paste volume = 11% for 24% void content for well compacted pervious concrete.

Paste volume = 18% for 24% void content for lightly compacted pervious concrete.

Paste volume, Vp = cement volume + water volume

$Vp = (c/3.15\text{x}1000\ kg/m^3) + w/1000\ kg/m^3$

Substituting $w = (w/cm)c$,

$Vp = c/(3.15\text{x}1000\ kg/m^3) + [(w/cm)c/1000\ kg/m^3]$

Therefore, $c = [(Vp/(0.315 + w/cm)] \times 1000\ kg/m^3$

(1) For well compacted pervious concrete,

$c = [0.11/(0.315 + 0.38)] \times 1000\ kg/m^3 = 158\ kg/m^3$

$w = (w/cm)c = (0.38 \times 158)\ kg/m^3 = 60\ kg/m^3$

(2) For lightly compacted pervious concrete,

$c = [0.18/(0.315 + 0.38)] \times 1000\ kg/m^3 = 259\ kg/m^3$

$w = (w/cm)c = (0.38 \times 259)\ kg/m^3 = 98\ kg/m^3$

E7 CALCULATION OF COARSE AGGREGATE PROPORTION

(1) For well compacted pervious concrete

(a) Volume of concrete = 1 m^3

(b) Void content = 24%

(c) Paste volume = 11%

(d) Volume of aggregate = 1-(0.24 + 0.11) = 0.65 m^3

(e) Mass of coarse aggregate = volume of coarse aggregate x specific gravity of coarse aggregate x 1000

= 0.65 x 2.70 x 1000

= 1755 kg/m^3

(2) For lightly compacted pervious concrete

(a) Volume of concrete = 1 m^3

(b) Void content = 24%

(c) Paste volume = 18%

(d) Volume of aggregate = 1-(0.24 + 0.18) = 0.58 m^3

(e) Mass of coarse aggregate = volume of coarse aggregate x specific gravity of coarse aggregate x 1000

= 0.58 x 2.70 x 1000

= 1566 kg/m^3

E8 MIX PROPORTIONS FOR TRIAL NUMBER 1 BASED ON AGGRGEATE IN SSD CONDITION

(1) For well compacted pervious concrete

Cement = 158 kg/m^3

Water = 60 kg/m^3

Coarse Aggregate = 1755 kg/m^3

Water-cement ratio = 0.38

(2) For lightly compacted pervious concrete

Cement = 259 kg/m^3

Water = 98 kg/m^3

Coarse Aggregate = 1566 kg/m^3

Water-cement ratio = 0.38

Note: The necessary changes in the water and aggregate content shall be made as given in **Clause 7** as per the condition of aggregates.

ANNEXURE F

ILLUSTRATIVE EXAMPLE ON PERVIOUS CONCRETE MIX PROPORTIONING

An example illustrating the mix proportioning for pervious concrete of M10 grade having minimum percolation rate of 350 mm/min using 5 per cent fine aggregate.

F1 STIPULATIONS FOR PROPORTIONING

a) Grade designation — M10

b) Type of cement — OPC 43 grade conforming to IS:269

c) Maximum nominal size of aggregate — 9.5 mm

d) Minimum percolation rate — 350 mm/min

F2 TEST DATA FOR MATERIALS

a)	Cement used	OPC 43 grade conforming to IS:269
b)	Specific gravity 1) Cement 2) Coarse aggregate 3) Fine aggregate	 3.15 2.70 2.62
c)	Water absorption 1) Coarse aggregate 2) Fine aggregate	 0.5 per cent 1.0 per cent
d)	Free (surface) moisture 1) Coarse aggregate 2) Fine aggregate	 Nil (absorbed moisture also nil) Nil (absorbed moisture also nil)
e)	Fine aggregate	Conforming to grading Zone II as per IS:383

F3 DESIGN COMPRESSIVE STRENGTH FOR MIX PROPORTIONING

$f'_{ck} = f_{ck} + 1.65\ S$

Where

f'_{ck} = target mean compressive strength at 28 days,

f_{ck} = characteristic compressive strength at 28 days, and

S = standard deviation of compressive strength.

From **Table 18**, standard deviation, S = 2.5 N/mm².

Therefore, target strength,

$f'_{ck} = f_{ck} + 1.65\ S$

$= 10 + 1.65 \times 2.5 = 14.13$ N/mm²

F4 SELECTION OF WATER-CEMENT RATIO

The conventional water cement ratio v/s compressive strength relationship for normal concrete does not apply to pervious concrete.

Let us take water cement ratio = 0.38 for the first trial.

F5 VOID CONTENT

From **Table 19**, void content = 25% for percolation rate of 350 mm/min

From **Table 20**, void content = 23% for compressive strength of 14.13 N/mm^2

Let us take an average value of 24% to satisfy the requirement of percolation rate and compressive strength.

F6 PASTE VOLUME (Vp), CEMENT CONTENT (c) AND WATER CONTENT (w)

From **Table 21**, paste volume = 11% for 24% void content for well compacted pervious concrete.

This paste volume has to be reduced by 1% for 5% fine aggregate of the total aggregate.

Therefore, paste volume = 10% for well compacted pervious concrete

Paste volume = 18% for 24% void content for lightly compacted pervious concrete.

This paste volume has to be reduced by 0.5% for 5% fine aggregate of the total aggregate.

Therefore, paste volume = 17.5% for lightly compacted pervious concrete.

Paste volume, Vp = cement volume + water volume
Vp = (c/3.15 x 1000 kg/m^3) + w/1000 kg/m^3

Substituting w = (w/cm)c,
Vp = c/(3.15 x 1000 kg/m^3) + [(w/cm)c/1000 kg/m^3]

Therefore, c = [(Vp/(0.315 + w/cm)] x 1000 kg/m^3

1) For well compacted pervious concrete,

c = [0.10/(0.315 + 0.38)} x 1000 kg/m^3 = 144 kg/m^3
w = (w/cm) c = (0.38 x 144) kg/m^3 = 55 kg/m^3

2) For lightly compacted pervious concrete,

c = [0.175/(0.315 + 0.38)} x 1000 kg/m^3 = 252 kg/m^3
w = (w/cm) c = (0.38 x 252) kg/m^3 = 96 kg/m^3

F7 CALCULATION OF COARSE AGGREGATE PROPORTION

(1) For well compacted pervious concrete

(a) Volume of concrete = 1 m^3

(b) Void content = 24%

(c) Paste volume = 10%

(d) Volume of aggregate = 1-(0.24 + 0.10) = 0.66 m^3

(e) Mass of coarse aggregate = d x volume of coarse aggregate x specific gravity of coarse aggregate x 1000

= 0.66 x 0.95 x 2.70 x 1000

= 1693 kg/m^3

(f) Mass of fine aggregate = d x volume of fine aggregate x specific gravity of fine aggregate x 1000

= 0.66 x 0.05 x 2.62 x 1000

= 86 kg/m^3

(2) For lightly compacted pervious concrete

(a) Volume of concrete = 1 m^3

(b) Void content = 24%

(c) Paste volume = 17.5%

(d) Volume of aggregate = 1-(0.24 + 0.175) = 0.585 m^3

(e) Mass of coarse aggregate = d x volume of coarse aggregate x specific gravity of coarse aggregate x 1000

= 0.585 x 0.95 x 2.70 x 1000

= 1500 kg/m^3

(f) Mass of fine aggregate = d x volume of fine aggregate x specific gravity of fine aggregate x 1000

= 0.585 x 0.05 x 2.62 x 1000

= 77 kg/m^3

F8 MIX PROPORTIONS FOR TRIAL NUMBER 1 BASED ON AGGRGEATE IN SSD CONDITION

(1) For well compacted pervious concrete

Cement = 144 kg/m^3

Water = 55 kg/m^3

Coarse Aggregate = 1693 kg/m^3

Fine Aggregate = 86 kg/m^3

Water-cement ratio = 0.38

(2) For lightly compacted pervious concrete

Cement = 252 kg/m^3

Water = 96 kg/m^3

Coarse Aggregate = 1500 kg/m^3

Coarse Aggregate = 77 kg/m^3

Water-cement ratio = 0.38

Note: The necessary changes in the water and aggregate content shall be made as given in **Clause 7** as per the condition of aggregates.

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